Advanced Leak Detection Lidar (ALDL), 8th Quarterly Report

Date of Report: *August 31, 2015*

Contract Number: *DTPH56-13-T-000004*

Prepared for: *DOT, PHMSA*

Project Title: *Advanced Leak Detection Lidar*

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For quarterly period ending: *August 31, 2015*

1.0 Funds and Work Completed During this Quarterly Period

This report covers the eighth 3 month period of the research effort. A summary of the project-to-date cost history, which ties to the Delivery Milestones, is provided in **Figure 1**, below. The variance in Q8 is the result of delays with completion of the steering mirror, some software integration and lab testing, which pushes final flight testing to the end of September.

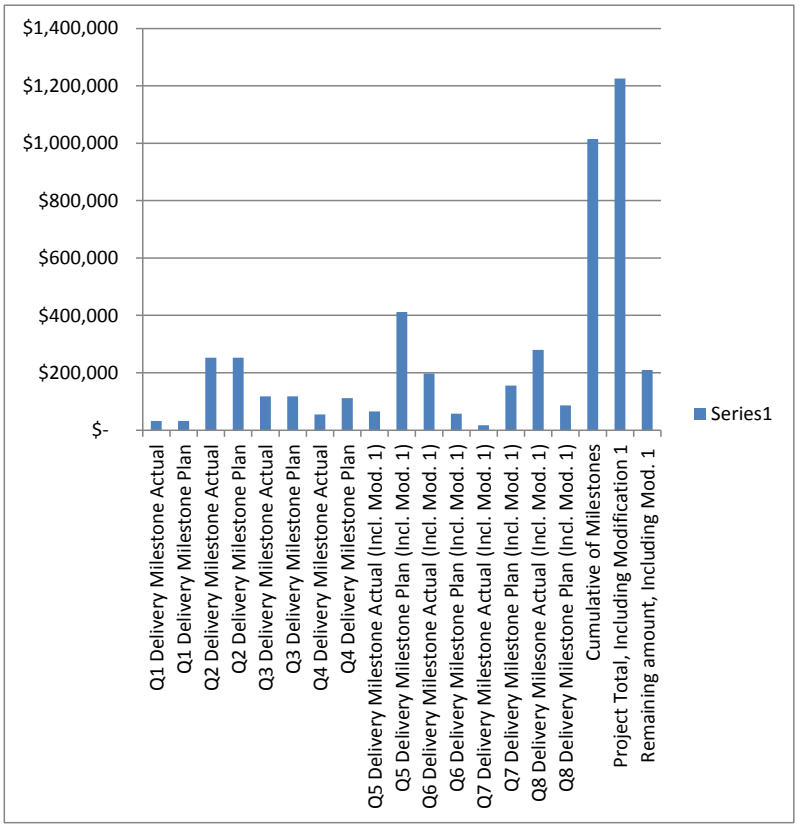

Figure 1, Achievement of payment milestones through the 8th quarter.

2.0 Progress Against 7th Quarter Delivery Milestones

Summary of Progress: Overall progress has been very good this quarter.

- The lasers, which had been greatly delayed, were delivered in June.

- Higher-level instrument integration has progressed well; to the point that initial differential measurements of propane gas have been accomplished using the gas cell within the laser monitor box.

Two new issues have come up that are impacting the schedule for completion of some other milestones and are causing a delay of flight testing by about a month:

- The first is with laser electronics.

- The second is with the mechanical actuators in the steering mirror sub-assembly.

The table below summarizes progress against recent and current key milestones that are due for completion in Quarters 5 - 8. The black Xs indicate the planned completions. Green Xs indicate completions (early, on-time or late, but done) and the red Xs indicate re-planned completions.

Key Milestone Delivery Number & Name	Q5	Q6	Q7	Q8	Q9	Notes
D18, Procure laser transmitter components	X			X		Laser assembly delivered in Q8.
D32, Start pointing SW		X		X		Delayed until after WASM HW delivery to optimize development efficiency.
D25, Integration of transmit components			X	X		This was dependent on laser delivery (D18)
D26, Integration of receive components			X	X		This was done in close conjunction with D25, above, for maximum efficiency.
D27, Final alignments			X	X		This was dependent on laser delivery (D18)
D34, Pointing control SW complete			X		X	Delayed pending WASM HW delivery
D35, WASM completion			X		X	Delayed as part of "bath-tub" strategy while lasers were completed, but now impacted by a magnet component manufacturing issue.
D29, Lab demonstration testing.opment				X	X	Being impacted by modulation issue with lasers.
D30, Flight demonstration				X	X	Linked to lab demonstration test, above.
D31, Final report				X	X	Linked to all of the above milestones.

The following paragraphs provide specific information for all milestones completed or missed this quarter.

Figures 2-1 through 2-4 show key progress this quarter.

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Figure 2-1. The Large Aperture, Wide Angle Steering Mirror (LA-WASM) mechanism assembly has begun. A critical manufacturing step is the press-fit insertion of flex pivots that allow for mirror motion. The first flex pivot is pictured, above, after insertion.

Photo omitted from public version of the report

Figure 2-2, (Right) The Transceiver Module Extension is shown on the right. It accommodates the LA-WASM steering mirror has been fabricated and integrated with the rest of the transmit and receive optical transceiver module. The context camera has been moved into the extension and the IMU has been installed. The WASM mechanism and its control electronics board are not yet installed. (Left) The precision GPS receiver and navigation computer are now included in the ALDL equipment rack.

Photo omitted from public version of the report

Figure 2-3, The Laser Monitor Box is mounted on the rear side of the equipment rack and is being used extensively in conjunction with testing the algorithms differential detection. EMI-protected signal inputs have been added to the electronics.

Photo omitted from public version of the report

Figure 2-4, The original portion of the Transceiver Module (WASM "Extension not shown) is fully integrated and aligned. An optical block is in front of the off-axis parabolic reflector (lower right) to prevent spurious laser light impinging on the detector. A cooling fan has been added to the TEC fins (top right). All alignments, wiring tie-downs, and temperature sensors are installed.

2.1 Completed Milestones:

Delivery Milestone D28. Task T1 Technical Management (Accomplished): Task T1 is the ongoing, level-of effort to organize and manage the project with associated contractual delivery milestones each quarter. Key items for the 8th quarter are:

- Monthly and Quarterly Reports prepared and submitted.
- Technical management coordinated and lead effort associated with completed (and delayed) technical milestones described subsequently in Sections 2.1 and 2.2
- Commercialization activities continue. Section 3.0 provides details of the commercialization and additional resource matching expended through Q8 in this area.

Delivery Milestone D18. Task T4, Procure Laser Transmitter Components (Accomplished): The laser assembly was delivered at Ball on Monday, June 8th, 2015. Two days of check-out were done with the lead engineer from the laser supplier working side-by-side with Ball personnel in our lab. Key laser performance characteristics, including power and spectral purity were measured. The ability to fine-tune the wavelength was also re-verified after delivery.

Delivery Milestone D25. Task T15, Mechanical and Electrical Integration of Transmitter Components (Accomplished): Once the laser assembly had been received, the mechanical and electrical integration of the transmitter components could be completed. This included rack-mounting of the laser assembly, integration of its power supply, and provision of software and electrical interfaces to allow configuration of the laser: commanding the wavelength and intensity modulation frequencies.

Delivery Milestone D26. Task T16, Mechanical and Electrical Integration of Receiver Components (Accomplished): All of the receive path components have been mechanically and electrically integrated. This includes the electrical interfaces that supply power to the primary detector, support the detector thermo-electric cooling and connect the detector signal output to the signal processing electronics.

Delivery Milestone D27. Task T17, Final Alignments and Test Set-Up (Accomplished): Fine alignment of both the transmit and receive paths was accomplished. The transmit path columnation was achieved and light input to the receive telescope is focused on the single-pixel detector.

Delivery Milestone D32. Task T23, Initiate Pointing Control and Geo-Location Software Development Start (Accomplished): This activity has been started. Two major software packages (processes) are being ported from the earlier TotalSight development for use on ALDL. These include:

1) A "stripped-down" version of the Lidar Processor Software (LPSW) which accepts target coordinates, monitors GPS and IMU data and points and scans the steering mirror to direct the lasers and telescope look direction. This LPSW is being ported from its original operating system to the ALDL electronics which are running a different operating system .
2) The Lidar Viewer software. This software plots aircraft position and defines the targets (pipeline location). It does this in real time to show the progress of the aircraft along the pipeline. It also displays resulting data from the ALDL milestone.

Part of this milestone is to move the Ball-owned precision GPS receiver and IMU into the ALDL lab environment. These items are now installed. Figures show the IMU and navigation computer and GPS receiver unit, mounting.

2.2 Missed/Remaining Milestones

Delivery Milestone D16. Task T20, Industry Conference Paper and Presentation (Not Accomplished): This milestone was placed on the schedule as a placeholder. We believe that test results from the initial lab demonstration are needed before an abstract and paper for an industry conference should be put forward. We are considering the American Petroleum Institute pipeline industry meeting in April of 2015 as a presentation forum.

Delivery Milestone D34, Task D23, Pointing Control and Geolocation Software Development: Finish (In-Work/Not Accomplished): Great progress on this software has been achieved as described in Section 2.1 (Delivery Milestone D32). However, this task can't be considered complete until after the WASM has been integrated into the ALDL instrument and software control of the mirror pointing angles is demonstrated. This activity is expected to be completed in September, 2015.

Delivery Milestone D35, Task D24, WASM Fabrication, (In-Work/Not Accomplished): All of the WASM parts are complete except for the electromagnet actuators. The fabrication was delayed in Q7 as part of the "bath-tub" strategy to conserve budget until a reasonable level of effort across all aspects of the project could be sustained. The final tasks for WASM Fabrication were re-started in June. However, manufacturing problems arose with the magnetic cores of the electromagnetic actuators for the mechanism. These parts are being re-built and are due for delivery on September 10th. Thereafter, WASM completion is expected within one to two weeks. So, this milestone is delayed by one month, until September of 2015.

Delivery Milestone D29, Task T18, Lab Demonstration Testing (In-Work/Not Accomplished): Lab Demonstration Testing began in earnest at the end of July and was expected to have been completed by the end of Q8. Initial testing has used the gas cell within the Laser Monitor box to test the lasers and signal processing algorithms working together.

Measurement performance to date: The gas cell contains an amount of propane equivalent to 100,000 ppm-m. Performance has been poorer than targeted thus far. Based on these preliminary results, the instrument will detect surface contamination by oil and other hydrocarbons because liquid and solid phase material has a very strong signature. It will also detect and locate vapors evolving from gross leaks.

Measurement issue description: The main problem with the measurement is with the electronics within the lasers.

Corrective actions tried and in-work: We have confirmed the issues with the laser electronics and have tried working-around the issues by making adjustments to the signal processing software.

Ultimate solution: The ultimate solution is to address the root-cause of the measurement error by modifying the hardware. A corrective action plan has been developed and is being reviewed with the laser supplier, as well as internally at Ball. Our plan is to have this corrective action completed in time to support flight testing in late September.

Completion of the Lab Test milestone also depends on using the primary, cooled detector within the transceiver module to directly observe targets in the laboratory. All of the above progress was made using the propane gas cell in the Laser Monitor Box. Lab testing should be completed by mid-September, after the software upgrades are implemented to improve signal processing.

Delivery Milestone D30, Task T21, Flight Demonstration Testing (Not Accomplished): Flight testing is delayed pending completion of the WASM and lab testing. The flights are now slated for late September or early October. This milestone is being accomplished under the Colorado Advanced Industries Accelerator program. The University of Colorado is coordinating flight testing and setting-up ground targets and establishing the ground truth for comparison with the ALDL instrument's data. Ball is collaborating with CU on planning and will be supporting aircraft installation and instrument operation. Ball is also providing the ground test site (property) for the target locations.

Delivery Milestone D31, Task T19, Final Report (Not Accomplished): The final report cannot be completed until after the lab testing and flight testing have been done. So, this is delayed until mid-October.

3.0 Commercialization Update

Note that the commercialization activities are not funded under the contract and, instead, are included as part of the Resource Matching contained in the proposal. Commercialization activities are ongoing. Several contacts are being maintained with targeted end-user customers. Ball representatives have registered for the Geospatial Information Technology Association (GITA) "Pipeline Week" conference in The Woodlands, Texas. This conference runs from 9/15 through 9/17. Numerous gas operators will be present. Papers are being presented on competing (and lesser) leak detection technologies such as passive hyperspectral imaging and infrared imaging.

4.0 Schedule

The ALDL project has now slipped-schedule by 1 to 1.5 months.

Figure 4-1, on page 8, presents the updated project schedule. The plan is shown by the blue bars. Completed tasks are shown in green (even those that extended beyond their planned duration). Tasks with ongoing delays are highlighted by yellow bars where schedule slack is being consumed and a red bar where schedule impact is being incurred. The vertical red line on the schedule shows the current date.

5.0 Payment Milestones

Payment milestones D28, D18, D25, D26, D27 and D32 will be submitted for the seventh Quarter as summarized in Section 2.

Milestones D16, D29, D30, D31, D34 and D35 are the remaining milestones, all of which are targeted for completion in the 9th quarter of the project.

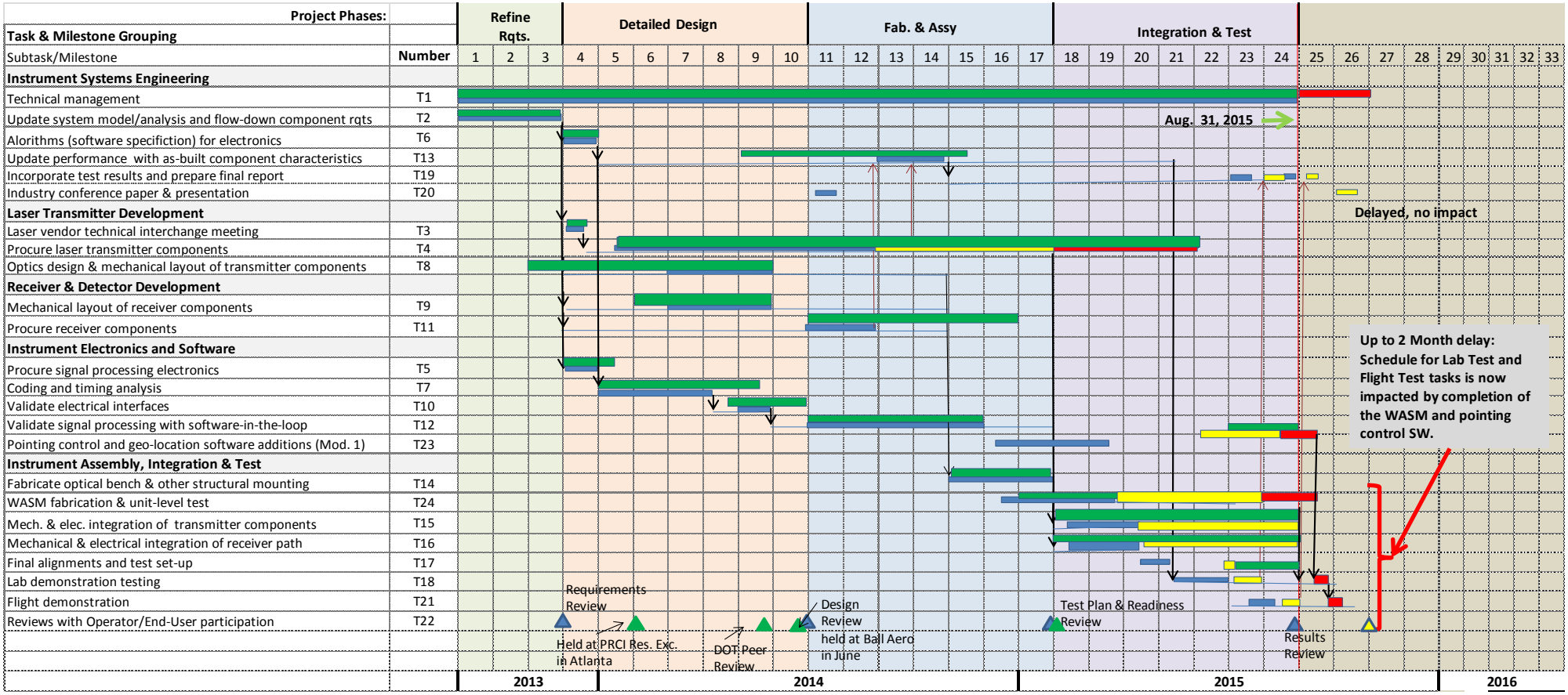

Figure 4-1, Advanced Leak Detection Lidar (ALDL) schedule progress against plan. Green bars indicate work accomplished. Yellow and red bars indicate delays. The vertical red line marks the end of the eighth quarter of the project (i.e. August 31, 2015). The schedule and list of tasks has been updated to account for Modification #0001. The tan period after the Integration and Test phase is included in the project period of performance and may be used for enhanced testing or refinements of the ALDL technology. At least one month of this "buffer" will be needed to complete the planned work due to delays from the WASM magnets and ongoing work to integrate pointing control and geo-location software.

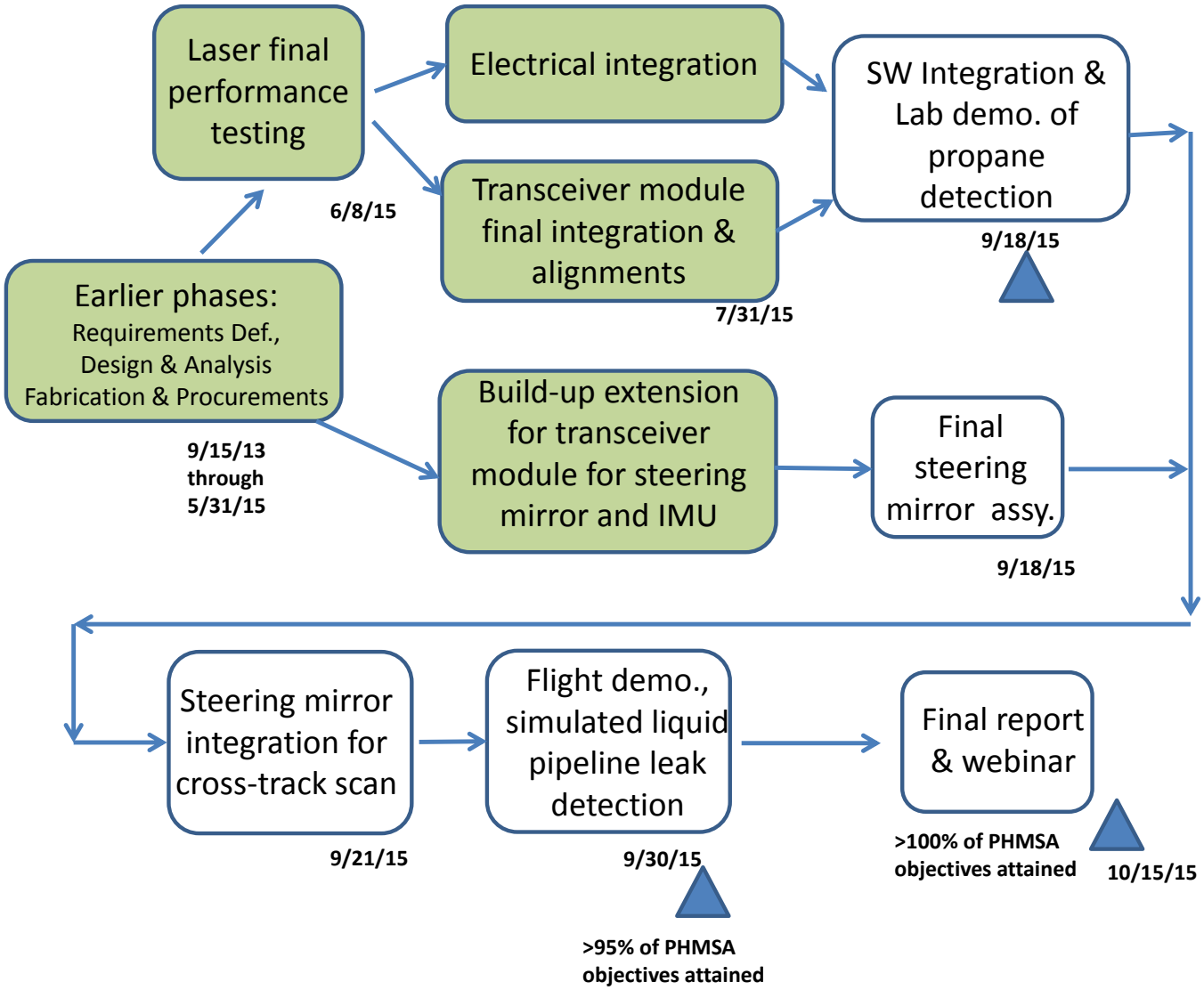

Figure 4-2, Simplified flow diagram of remaining project activities and tasks.